Analyzing and Predicting Thermal Comfort of Students in Primary School Classrooms of Composite Climate in India

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氏　　名　：Betty Lala

Name

論 文 名： Analyzing and Predicting Thermal Comfort of Students in Primary School Classrooms of Composite Climate in India

（インドの複合気候の小学校教室における児童の温熱快適性に関する分析と予測）

区　　分　：甲

Category

論 文 内 容 の 要 旨

Thesis Summary

The aim of this thesis was to determine the thermal comfort requirements for students of the primary school category. Thermal comfort is defined as a physiological condition that allows humans to maintain satisfaction with their environment. It is essential in primary schools since it allows teachers and children to be comfortable, which could lead to better learning outcomes, better ovover-allealth and also lower absenteeism rates. The motivation was also that the thermal comfort for primary school students and their perceptions inside their classroom environment, especially in the context of tropical climate of India, is lacking. In order to achieve a greater understanding of the thermal comfort requirements in this context, this study aimed to determine whether or not the students of primary schools in naturally ventilated classrooms of composite climate were comfort- able inside their classrooms during summer and winter season. The study highlights the essential findings from the field surveys conducted in 12 primary schools in Dehradun, India. Further, there was also a need to investigate the thermal comfort observations of the primary school teachers and to establish the risks that children are exposed due to high temperature. Evaluation of responses from 335 teachers' observations exposed that heat-related illnesses and symptoms are potentially a problem especially in schools with limited resources where providing air conditioners are not possible. In addition, the application of machine learning to predict thermal comfort for students was explored. It is now possible to address complex thermal comfort prediction problems due to developments in the domain of machine learning and the steadily declining cost of computational resources. This study proposed using support vector machine (SVM) to solve thermal comfort prediction and a real-life application of multi-task learning model, DeepComfort was proposed. The contributions of the research are summarized according to each chapter.

In chapter 1, the need for study of thermal comfort in primary schools of India was discussed. Despite it's huge population of school-going children (which is one-third of the population), the study of thermal comfort in Indian primary schools is limited. In addition, the current adult-based thermal comfort standards of ASHRAE II and ISO 7730 are not appropriate to assess children's thermal comfort. Further, the use of air conditioners is limited in schools as compared to technologically advanced countries, making the students even more vulnerable to the increasing global temperatures. The prevalence of disturbance caused by heat waves on students' health and learning in naturally ventilated classrooms further remains a challenge. With this background, the objectives of this thesis were to: a) to review thermal comfort literature extensively to understand the theoretical framework of research; b) to identify the risks to students' health and well-being during days of extreme heat inside classrooms; c) to identify the thermal comfort perceptions of primary school students in their naturally ventilated classrooms during winter and summer months and d) to investigate the applicability of machine learning based thermal comfort models to predict students' comfort perceptions. The conclusion of each objective is presented in detail ahead.

In Chapter 2, a theoretical overview of the study of thermal comfort was presented. Thermal comfort definition, standards, influencing factors, comfort models and indices were elaborated. Further, the current state of research in classroom thermal

comfort and the open problems that need to be addressed are discussed. Overview of development and application of data-driven machine learning (ML) techniques in thermal comfort studies from relevant research were presented next. Several aspects such as distribution of the MLTC studies across regions/climates, types of ML algorithms used, outputs considered, validation methodologies, etc., were discussed in detail. The need for real-world implementation of machine learning based thermal comfort prediction was proposed.

Chapter 3 the potential problem and vulnerability of student's exposure to high temperatures and heat risk inside their classrooms was examined. The dangerous exposure of heat wave conditions among primary school students was explored through exploratory questionnaire survey from 335 primary school teachers. 35 primary schools, both government-funded and private schools, spread across seven cities of hot and dry climatic region were selected for the survey. The surveyed were Delhi (average temperatures 40 °C), Jaipur (40°C), Ajmer (39.7°C), Udaipur (41°C), Vadodara (39.5°C), Ahmedabad (41°C) and Pune (42 °C). It was found that both teachers and students are exposed to extremely high temperatures and exposure to heat stress could result in negative ill effects and directly by impacts on their well-being. It is also significant to note that the schools must encourage to raise awareness about heat waves and heat stress among teachers and also educate how to cope and detect the dangers of heat stress among students and their parents. Therefore, regular training on heat waves must be made mandatory and increased education on how to reduce these risks must be made available to all teachers.

Chapter 4 presents analysis of data gathered through month-long questionnaire surveys con- ducted in naturally ventilated primary school buildings of Dehradun, India. Responses from 14 classrooms (5 schools) during winter and 21 classrooms (7 schools) during summer season was collected during the field surveys. The aim and objective of the study was to understand and analyze student's thermal comfort perceptions and the risks they face within their classroom environment. One key finding was that, according to standard ASHRAE 55, only 6% of the samples from the summer survey were under an 80% thermal acceptability range, but the indoor thermal conditions of the assessed classrooms were outside of the comfort range for an 80% acceptability limit during the winter study survey. Additionally, 95.1% of the samples from the summer survey had HIs above 91 degrees Fahrenheit, which indicates a heat risk category of either "extreme caution" or "danger." The results imply that children's assessments of thermal sensations and thermal satisfaction don't reflect the environment's actual physical characteristics. Furthermore, despite being in an environment with extremely high temperatures, several of the students reported that they were satisfied with the thermal environment. In total, 95.1% of the responses that were "very satisfied," "satisfied," or "slightly satisfied" were collected under the condition of "extreme caution" or "danger" in terms of heat risk. The student's statement that of being thermally satisfied cannot be taken as accurate considering that the summertime temperatures inside the classrooms were fairly high, increasing the risk of heat stroke and the negative impacts of heat-related illness to children. It was also concluded from the study that achieving thermally comfortable classrooms is crucial for improving students' general health, productivity, and academic results, particularly in Indian primary schools. Lastly, the results of the survey suggest that the widely accepted adult based comfort standards do not accurately predict thermal comfort for students in Indian composite climate context.

Next, Chapter 5, provides a comprehensive review on the application of Machine Learning (ML) techniques in thermal comfort studies. By leveraging the use of machine learning, the study discussed two methodologies to predict and analyze students thermal comfort perceptions, i.e., Support Vector Machine (SVM) and DeepComfort. Dataset collected from winter surveys was used to train, while also comparing the results with the extensive comfort data provided by the ASHRAE Global Thermal Comfort Database II. Firstly, the Support Vector Machine (SVM) models were trained and three objectives were to ascertain : (i) The impact of spatial variability on classification model performance for individual schools, (ii) The generalization ability of the models across schools, and (iii) Spatial context of feature importance. For this, SVM models were trained and tested on each individual school's data and feature importance was reported. Data for each individual school was considered during training and a school-specific test performance was also reported. Lastly, $(n - 1)$ schools were considered during training and test performance was reported on the nth school. The results show that the generalization ability of SVM based thermal comfort models is not very high but it is quite stable (low variation). Further, the spatial school-specific models also show to outperform generalization models in all cases.

Secondly, a real-world implementation of the proposed multi-task learning model , called DeepComfort is proposed. The model aims to address the problem of multiple TC prediction models, one specific to each metric. Concurrently, it predicts three TC metrics, viz, TSV (sensation), TCV (comfort), and TPV (preference). Deepcomfort is shown to outperform 6 single-task learning models, namely Support Vector Machine (SVM), Random Forest, Decision Tree, k-nearest neighbors algorithm (KNN), Adaptive Boosting (Adaboost) and deep neural network (DNN). Despite the difficulties posed by illogical votes, the deep network architecture of DeepComfort enables it to maintain high prediction accuracy for the primary student data as well as ASHRAE II data, which ensures high generalization capability. The DeepComfort model also exhibits consistent performance for different categories of categorical features with different features.